CALIBRATION OF WASP5 FOR HYDRODYNAMIC TRANSPORT IN BACK BAY OF BILOXI

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INTRODUCTION AND PURPOSE

The development of hydrodynamic and water quality models for Back Bay of Biloxi was initiated in response to an increasing need for a comprehensive water quality model that will facilitate decision-making in the overall management activities of the Bay estuarine system, including assessment of existing water quality, estimation of waste assimilative capacity under various conditions and seasonal variations, and analysis of the effect of waste discharge into the Bay. The Water Quality Analysis Simulation Program-5 (WASP5) was chosen for application to Back Bay of Biloxi (Ambrose et al. 1993). This model is capable of interpreting and predicting water quality responses to natural phenomena and man-made pollution. WASP5 system consists of three stand-alone computer programs, DYNHYD5, EUTRO5, and TOXI5 that can be run conjunction or separately. The hydrodynamics program, DYNHYD5 simulates the movement of water, while the water quality program, EUTRO5, simulates the movement and interaction of pollutants within the water.

In the hydrodynamic calibration using DYNHYD5, tide level and velocity were collected and used for model calibration. Velocity determination took the form of two approaches: velocity measurements at several transects and salinity measurements (as conservative substance) at several stations. Transport mechanisms of the Bay characterized by the dispersive transport was determined by employing EUTRO5.

The study area is located along the Mississippi Gulf Coast and is adjacent to Jackson and Hancock Counties (Figure 1). Also included in the study area are the metropolitan areas of Biloxi, Gulfport, Ocean Springs, and D'Iberville.

The initial model calibration was accomplished utilizing historical data collected during the periods of July 28-August 2, 1972, and June 14-16, 1977 (Shindala et al. 1996). Final model calibration was performed utilizing a set of field data acquired on the Back Bay of Biloxi, during September 12-21, 1994. Model verification was conducted against another set of field data taken in the Bay during April 25 - May 2, 1995. This paper presents the details of the implementation of the hydrodynamic modeling framework together with results of the hydrodynamic calibration and verification efforts. Details of the water quality calibration effort are discussed in the Completion Report (Shindala et al. 1996) and reference (Shindala et al. 1999).

HYDRODYNAMIC MODEL COMPUTATIONAL METHODOLOGY

The computational procedure developed in the DYNHYD5 program is based on the solution of one-dimensional equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). It is also based on the conventional Saint-Venant equations that describe one-dimensional unsteady flow in an open channel. Prediction of water velocities and flow can be made based on the conservation of momentum by using the equation of motion.

Expressing the principle of conservation of mass applied to an elemental reach of a prismatic channel with rectangular cross-section, the equation of continuity has the following form:

$$\frac{\partial H}{\partial t} + D\frac{\partial U}{\partial x} = 0 \tag{1}$$

where H is the water surface elevation (head) (m), D is the water depth (m), U is the longitudinal velocity (m/sec), t is the time (sec), and x is the longitudinal distance (m).

Based on the conservation of volume, prediction of water heights (heads) and volume of every segment in the model network can be made using the equation of continuity. The equation of motion can be derived from the principle of conservation of energy, or momentum. The equations of motion and continuity used in DYNHYD5 are presented below (Ambrose et al. 1993):

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} + a_{g\lambda} + a_f + a_{w\lambda} \tag{2}$$

$$\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x} \quad OR \quad \frac{\partial H}{\partial t} = -\frac{1}{B}\frac{\partial Q}{\partial x} \tag{3}$$

where the first term on the left side of the equation (2) is the local inertia term, or the velocity rate of change with respect to time (m/sec^2); the first term of right side of equation (2) is the Bernoulli acceleration, or the rate of momentum change by mass transfer; also defined as the convective inertia term from Newton's second law, (m/sec^2); $a_{g,\lambda}$ is gravitational acceleration along the axis of the channel (m/sec^2); a_f is frictional acceleration (m/sec^2); $a_{w,\lambda}$ is wind stress acceleration along axis of channel (m/sec^2); x is distance along axis of channel (m); t is time (sec); U is velocity along that axis of channel (m/sec); λ is longitudinal axis; g is acceleration gravity (m/sec^2); A is cross-sectional area of a segment (m^2); Q is flow (m^3/sec); B is width (m); H is water surface elevation (m); $\partial H/\partial t$ is rate of water surface elevational change with respect to time (m/sec); $\partial Q/B\partial x$ is rate of water volume change with respect to distance per unit width (m/sec).

Equations (2) and (3) form a basis for the hydrodynamic model, and their solutions give the velocities and heads throughout the water body over the duration of model simulation. The "link-node" network is used in this model to solve the equations of motion and continuity at alternating points. At each time step, the equation of motion is solved at the links, giving velocities for mass transport calculations, and the equation of continuity is solved at the nodes, giving heads for pollutant concentration calculations.

The equations of motion and continuity have to be written in a finite difference form, as shown below, in order to apply them to a link-node computational network (Ambrose et al. 1993).

$$\frac{U_i^t - U_i}{\Delta t} = -U_i\frac{\Delta U_i}{\Delta x_i} - g\frac{\Delta H_i}{\Delta x_i} - \frac{g n_i^2}{R_i^{4/3}}U_i|U_i| + \frac{C_d}{R_i}\frac{\rho_a}{\rho_w}W_i^2\cos\Psi_i \quad (4)$$

$$\frac{H_j^t - H_j}{\Delta t} = -\frac{\Delta Q_j}{B_j\Delta x_j} \quad (5)$$

where U_i^t is the velocity in channel i at time t (m/sec); Δx_i is the channel length (m); Δt is the time (sec); i is channel or link number; $\Delta U_i/\Delta x_i$ is velocity gradient in channel i with respect to distance (sec^{-1}); $\Delta H_i/\Delta x_i$ is water surface gradient in channel i with respect to distance (m/m); j is junction or node number; C_d is the drag coefficient (assumed to retain constant value of 0.0026) (dimensionless); n_i is Manning's roughness coefficient (sec/m$^{1/3}$); R_i is hydraulic radius; ρ_a and ρ_w are the density of air and water respectively (kg/m^3); W_i is the wind speed (relative to the moving water surface) measured at a height of 10 meters (m/sec); Ψ_i is the angle between the channel direction and the wind direction (relative to the moving water surface).

After preparing all input parameters in the network such as initial values for channel velocities and junction heads, boundary conditions for downstream heads, and forcing functions for freshwater inflow and wind stress, equations (4) and (5) in explicit finite difference form are solved using a modified Runge-Kutta procedure.

SEGMENTATION OF BACK BAY OF BILOXI

Segmentation of the Back Bay of Biloxi established for the hydrodynamic and water quality models is illustrated in Figure 1. Two-dimensional segmentation in the Bay was selected to represent the spatial heterogeneity of the water bodies in longitudinal and lateral directions. By using approximately equal surface areas, this segmentation is capable of representing the physical shape of the water system. The segmentation scheme used for both models does not include vertical resolution. Although there are indications of vertical variations in transport, the data reviewed to date does not include sufficient information to either establish the boundaries or to estimate exchanges between vertical layers. Finally, benthic layers are not incorporated in this effort due to the unavailability of data needed to simulate eutrophication with benthos. Thus, the model application will be for a two-dimensional vertically mixed system for the bay and one-dimensional vertically mixed system for the tributaries. Overall, the Back Bay of Biloxi was divided into 641 segments, including twenty-eight (28) model boundaries. Thirteen downstream boundary segments are required at Mississippi Sound and fifteen upstream segments are required at major river tributaries.

MODEL INPUT PARAMETERS

The initial input parameters of the hydrodynamic model DYNHYD5 include data for junctions (nodes) or segments, channels (links), freshwater inflows, downstream boundaries, wind and precipitation/evaporation. All of the parameters incorporated in the model were either temporal or spatial variables, or both. Since available data were not sufficient to define many of the variables mentioned above on an hourly basis, they were approximated by a series of piecewise linear functions.

Junction Parameters

The input parameters associated with junctions in DYNHYD5 are initial surface elevation (head), surface area, and bottom elevations. Segment volumes and mean depths are calculated internally using the above parameters. The initial water surface elevations were considered flat over the Bay and its associated tributaries with the exception of the Biloxi River. The water surface elevation at the model boundary of Biloxi River is 0.5 meter higher than the surface elevation at the Bay.

Channel Parameters

The input parameters associated with channels in DYNHYD5 are characteristic length, width, hydraulic radius or depth, channel orientation (from true north), initial velocity (v = 0.01 m/sec), and Manning's roughness coefficient (n = 0.03 sec/$m^{1/3}$).

Inflow Parameters

Inflows were specified at the upstream boundaries of the Biloxi River, Tchoutacabouffa River, Bernard Bayou, Turkey Creek, and Brickyard Bayou using measurements from freshwater inflow studies. For small bayous at Keegan Bayou, St. Martin Bayou, and Bayou Poito, the inflows were the same as that used in Brickyard Bayou, while for Fritz Creek the inflow is the same as in Bernard Bayou. Other small bayous, the inflow is considered to be zero. Constant discharges taken from field measurements were specified at the outfall and intake of Mississippi Power Co-Watson Steam Plants cooling water system.

Downstream Boundary Parameters

Variable tidal functions were specified for thirteen downstream (seaward) cell boundaries. The tidal was inputted into the model as high and slow slack heights versus time from measured field data.

Wind Parameters

The input parameters associated with wind accelerations are wind speed, wind direction, and channel orientation. The running averages of the wind speed and direction from two meteorological stations were inputted in the model. These stations are at Spoil Island Meteorological Station and Mississippi Power Company Meteorological Station and are shown in Figure 2.

Other Parameters

The precipitation effect was considered in the calibration phase but not in verification phase. Evaporation effect was not considered in both phases. The variable junction geometry and channel geometry data were not included in the DYNHYD5 calibration and verification phases.

HYDRODYNAMIC MODEL CALIBRATION AND VERIFICATION

Initial calibration of the hydrodynamic model (DYNHYD5) for the Back Bay of Biloxi was accomplished utilizing historical data (USEPA 1973; USGS 1978). Results of this initial calibration effort are discussed in the Supplement to Completion Report (Shindala et al. 1996). The results of simulation utilizing the September 12-21, 1994, and April 25-May 2, 1995, intensive survey data were considered as the final calibration and verification efforts, respectively.

When the DYNHYD5 model is fully equipped with the proper bathymetry geometry and boundary conditions, only one parameter remains to be specified (e.g. Manning's n bottom roughness). For this reason, it is prudent that the input conditions of the model do not diverge greatly from reality.

The first parameter to calibrate is the Manning's n bottom roughness which is adjusted first globally and then, if necessary, locally so as to reproduce the propagation of the tide, both for the range as the wave proceeds upriver, as well as for the high and low phase difference relative to some station whose tidal features are well-established. After the value of bottom roughness is roughly calibrated, the dispersion coefficient is the next parameter to be determined. This can be accomplished by comparing salinity time series data and spatial distributions, using DYNHYD5 with EUTRO5.

In the hydrodynamic calibration and verification using DYNHYD5, tide level and velocity were collected and used for model calibration. Velocity determination took the form of two approaches: velocity measurements at several transects and salinity measurements (as conservative substance) at several stations. Transport mechanisms of the Bay characterized by the dispersive transport was determined by employing EUTRO5. Details of water quality calibration effort using EUTRO5 are discussed in the Completion Report (Shindala et al. 1996) and reference (Shindala et al. 1999). However, the determination of dispersion coefficient using EUTRO5 will be discussed in this paper.

Database

General field data jointly collected by the Mississippi Department of Environmental Quality (MSDEQ), United States Geological Services (USGS), National Oceanic Atmospheric Administration (NOAA), and Mississippi Power Co-Watson (MSPWR Co-Watson) during the two study periods (September 12-21, 1994, and April 25-May 2, 1995) were used to calibrate and verify the hydrodynamic model, respectively. The locations and type of hydrodynamic sampling stations for the

September 12-24, 1994, and April 25-May 2, 1995, surveys are shown in Figure 2. As shown in Figure 2 (a), tidal stage measurements were conducted at Marsh Point, Channel Island, and Big Lake in the September 12-21, 1994, survey. Current velocity and direction were measured at six transects. Wind speed and direction measurements were made at Spoil Island Meteorological Station and Mississippi Power Company Meteorological Station. Measurement of stream flows at the upstream model boundaries of Biloxi River, Tchoutacabouffa River, Old Fort Bayou, Bernard Bayou, and Turkey Creek were conducted during the period September 13-20, 1994, by Mississippi DEQ.

In the April 25-May 2, 1995, survey, current velocity and direction were measured at three sites as shown in Figure 2(b). Water level measurements (transducer and stage from tape down methods) at the upstream boundaries of Biloxi River, Tchoutacabouffa River, Old Fort Bayou, Bernard Bayou, Turkey Creek, and Brickyard Bayou were conducted by Mississippi DEQ. The instantaneous measurements of freshwater inflows at the major upstream boundaries were also conducted in the survey. The bathymetry data used in the study were based on the data from several sources (COAM 1995; USGS 1978; OPC/Mississippi DEQ 1985).

Calibration and Verification Results of Hydrodynamic Model

The determination of Manning's n and the accuracy of cross-sections are the most important items to consider for hydrodynamic model calibration. Several Manning's n were adjusted slightly until the predicted results reasonably matched the observed data. After several adjustments, Manning's n of 0.03 was selected for use in the study. Since the segmentation of the model was provided by the Center for Ocean and Atmospheric Modeling (COAM), no calibration was made in this study with regard to grid size and cross-sectional characteristics for the study area.

Due to constraints of space, only sample profiles at some arbitrary selected segments are presented. As shown (Figures 3 and 4), the computed tide level reasonably matched the observed data at the sampling station in the calibration and verification phases. The velocity profiles at each transect and station were compared against observed data in the calibration and verification phases. The magnitude of computed data was found to be in the range of observed data at each of the sampling stations.

Initial estimates of the dispersion coefficients were determined from dye studies (USGS 1978) and plots of chlorides or salinity distribution as a conservative tracer. However, transport mechanisms of the Bay characterized by the dispersive transport was determined by employing EUTRO5. EUTRO5 complexity level 1 runs were made to simulate salinity as a conservative substance in order to estimate the magnitude of the dispersion coefficient. Several dispersion coefficients were evaluated in calibration and verification phases to test the sensitivity of the model to variations in dispersion coefficients. As shown in Figures 5 and 6, the model reproduces the observed salinity data very well under the low slack, high slack, mid-channel, and mid-ebb conditions at dispersion coefficient of 1 m^2/sec. However, results of the simulations using several dispersion coefficients revealed the insensitivity of EUTRO5 to changes in the dispersion coefficients.

CONCLUSION

A two-dimensionally vertically well-mixed system and real-time model consisting of linked hydrodynamic and water quality models was developed for the Back Bay of Biloxi in Mississippi. The predicted tide levels reasonably matched the observed tide level at sampling stations in the calibration and verification phases. The magnitude of predicted velocity data was found to be in the range of observed data at each sampling station. Results of simulations using several dispersion coefficients revealed the insensitivity of EUTRO5 to changes in the dispersion coefficient. A reasonably good fit of salinity clearly indicates that the model reproduces the principal transport mechanisms of the estuary.

Comparisons of the predicted and observed data are made qualitatively by using spatial and temporal comparisons. The response of model prediction calculations is consistent with trends of the observed data ranges, but not with absolute values in all cases.

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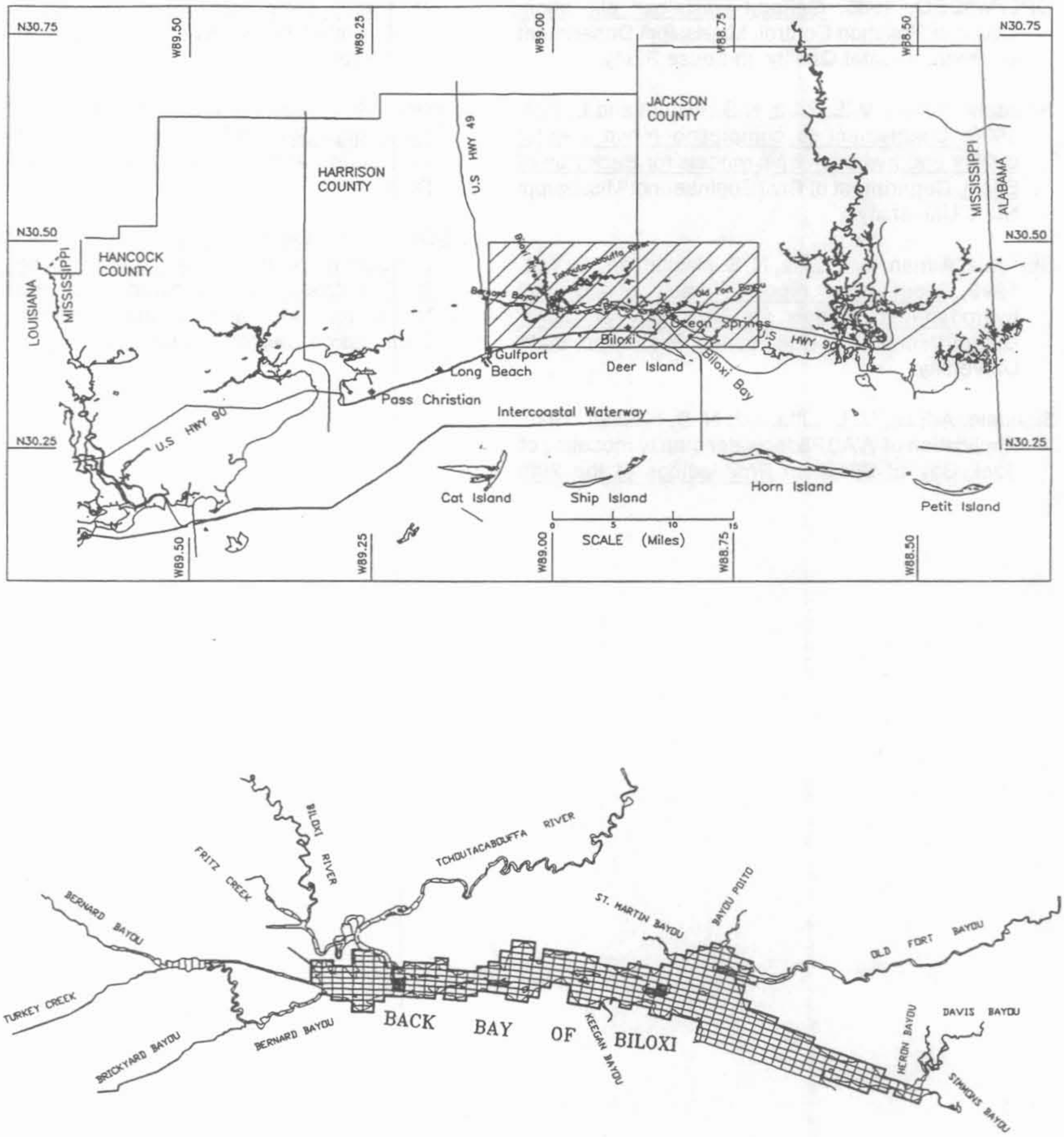

Figure 1: Location and Segmentation Map of Back Bay of Biloxi

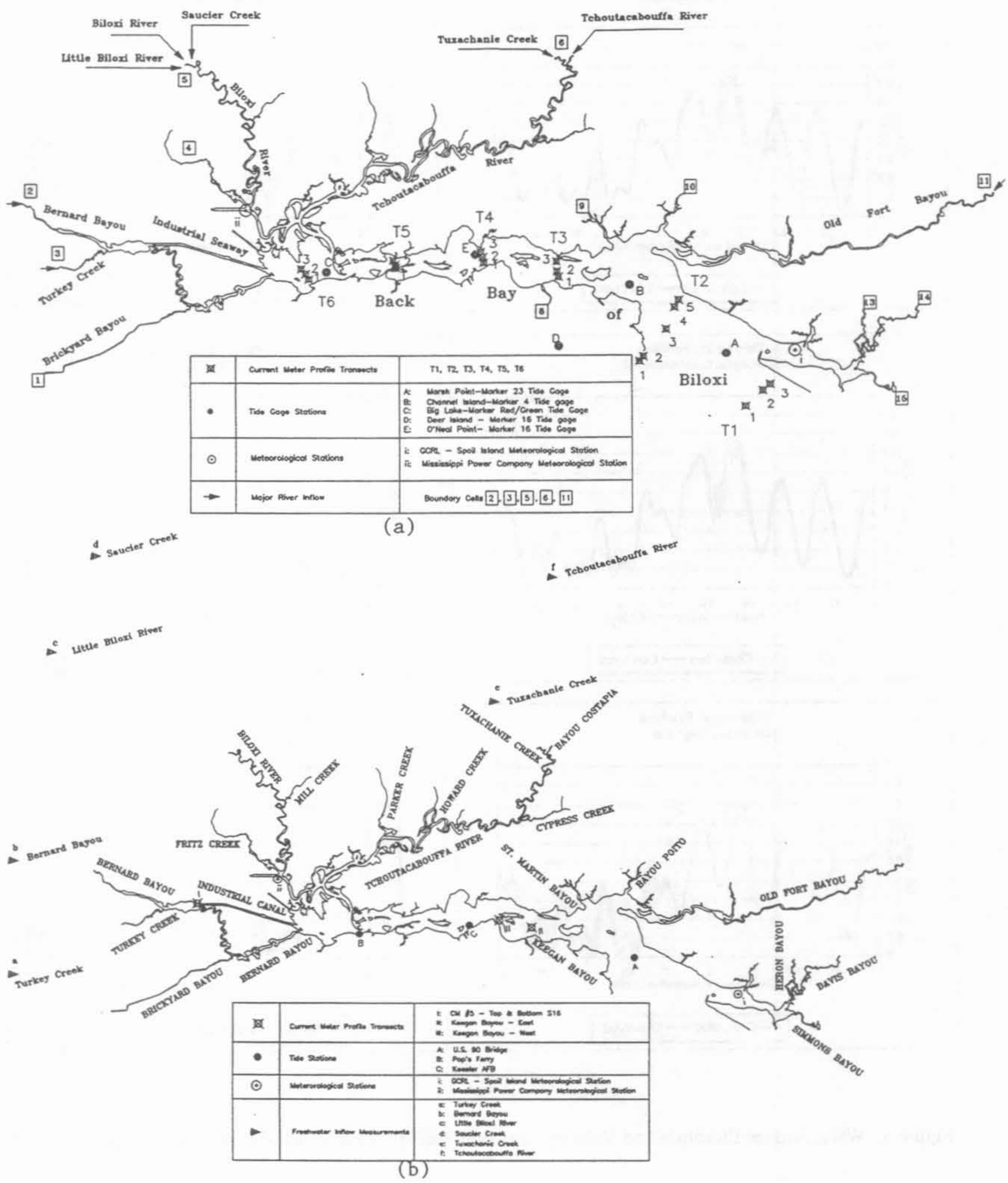

Figure 2:Location of Hydrodynamic Sampling Stations
(a) September 13-20, 1994 Study (b) April 25-May 2, 1995 Study

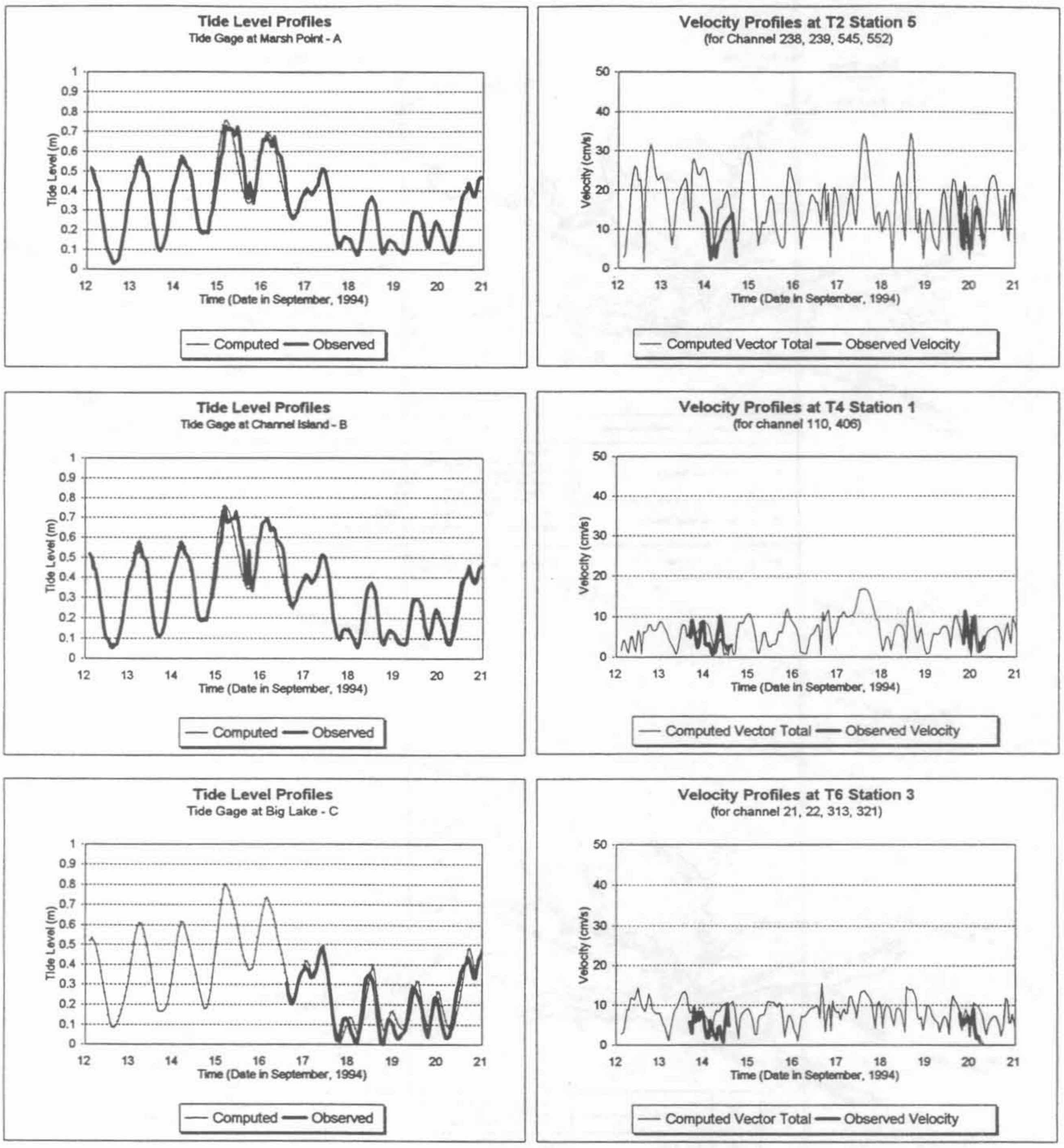

Figure 3: Water Surface Elevation and Velocity Temporal Profiles at Back Bay of Biloxi (September 12-21, 1994)

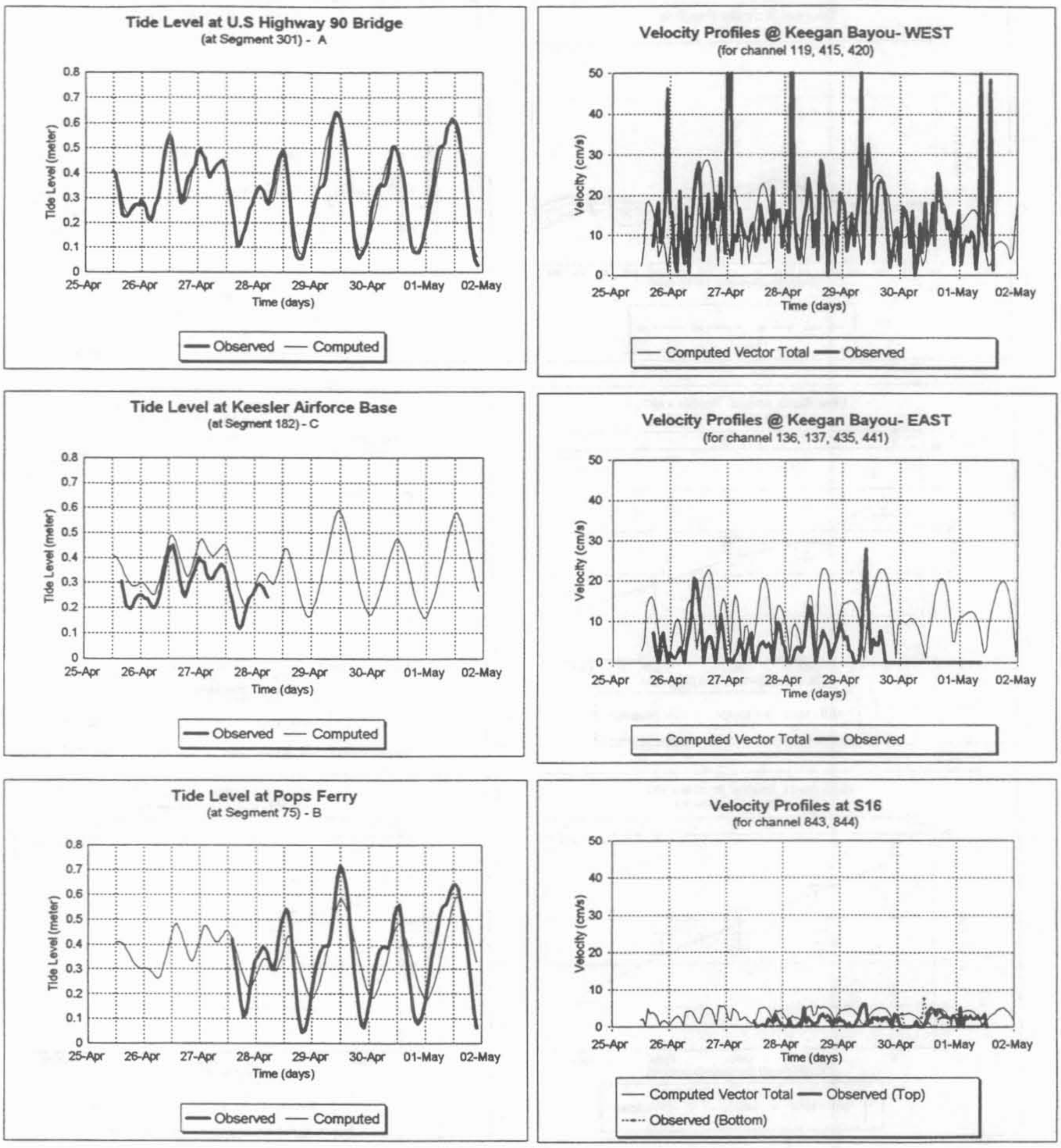

Figure 4: Water Surface Elevation and Velocity Temporal Profiles at Back Bay of Biloxi (April 25-May 2, 1995)

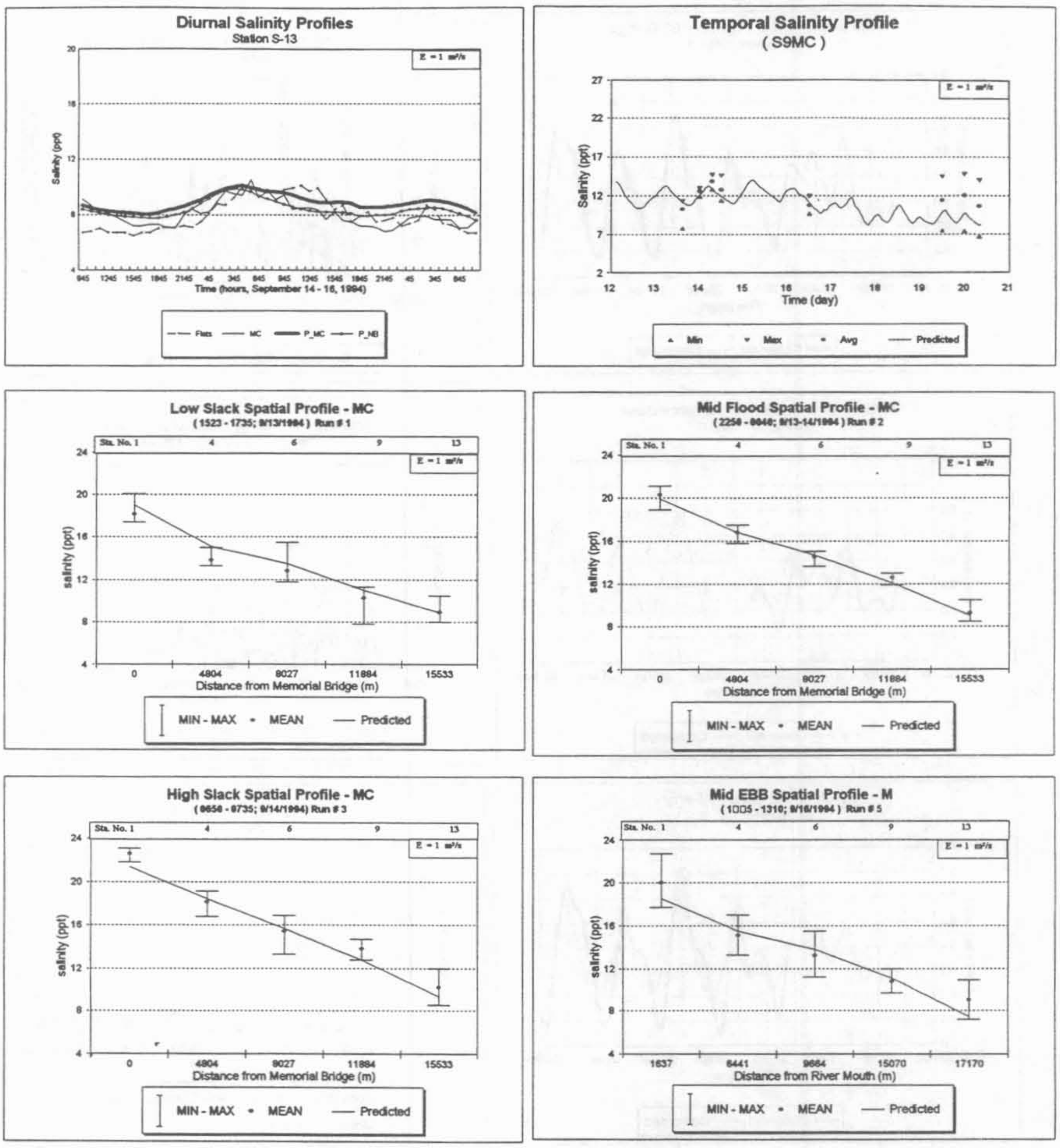

Figure 5: Salinity Spatial and Temporal Profiles at Back Bay of Biloxi (September 12-21, 1994)

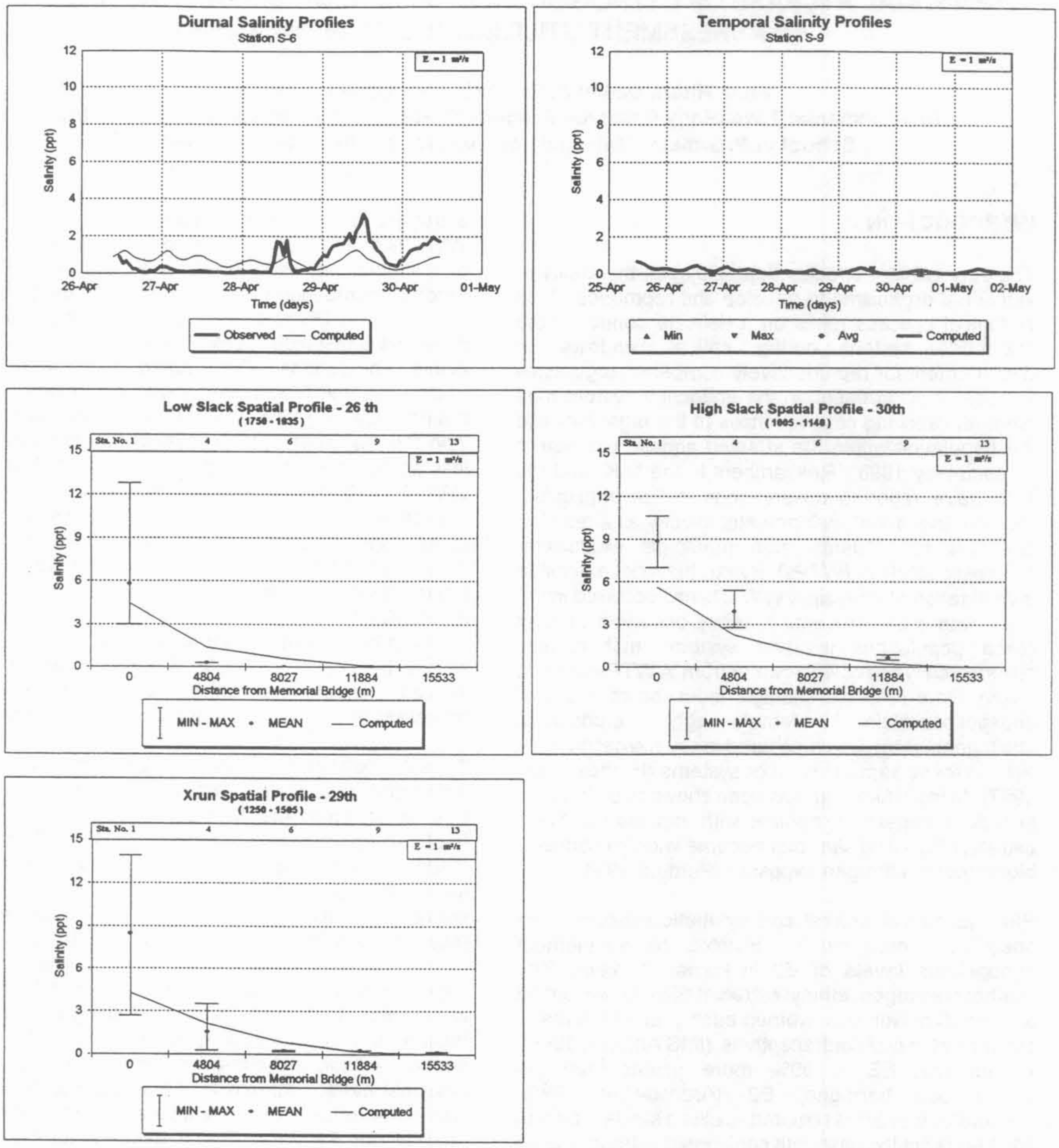

Figure 6: Salinity Spatial and Temporal Profiles at Back Bay of Biloxi (April 25 - May 2, 1995)